Chemical evidence of dairying by hunter-gatherers in highland Lesotho in the late 1st millennium AD

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Abstract

The recovery of Early Iron Age (EIA) artefacts and domestic animal remains from hunter-gatherer contexts at Likoaeng, Lesotho, has been argued to indicate contact between highland hunter-gatherers and EIA agropastoralist communities settled in lowland areas of south-eastern Africa during the second half of the first millennium AD. However, disagreement between archaeozoological studies and ancient DNA means that the possibility that those hunter-gatherers kept livestock themselves remains controversial. Here we report analyses of pottery-absorbed organic residues from two hunter-gatherer and one agriculturalist sites in highland Lesotho to reconstruct prehistoric subsistence practices. Our results demonstrate the exploitation of secondary products from domestic livestock by hunter-gatherers in Lesotho, directly dated to the seventh century AD at Likoaeng and the tenth century AD at the nearby site of Sehonghong. The data provide compelling evidence for the keeping of livestock by hunter-gatherer groups and their likely incorporation as ancillary resources into their subsistence strategies.

Introduction

Early Iron Age (EIA) populations who combined cereal and legume cultivation with livestock-keeping and almost certainly spoke Bantu languages began settling in southernmost Africa from the third century AD, initially focusing on the Woodland Savanna Biome of the region's summer rainfall zone[1-3]. Only in the early centuries of the second millennium AD did they begin to penetrate the grassland areas of Gauteng or northern KwaZulu-Natal, and effective occupation of the Highveld of the Free State and western Lesotho was not established until the seventeenth century. In contrast, the Maloti-Drakensberg Mountains of the remainder of Lesotho and the upland areas to its east along the uKhahlamba-Drakensberg Escarpment remained the domain of hunter-gatherer groups until the nineteenth century and the earliest farming villages along the upper portions of Lesotho's Senqu River (Fig. 1a) were not established until 1878[4]. Despite their geographical separation, rock art and historical accounts have long been cited as evidence of prolonged contact between Maloti-Drakensberg hunter-gatherers and agricultural populations in neighbouring areas[5-10]. On the farmer side of this equation, linguistic and cultural borrowings among both Nguni and South Sotho speakers attest to such contacts[11-13], as do more recent genetic studies that point to considerable admixture between hunter-gatherers and Bantu-speaking agropastoralist groups in south-eastern Africa[14-17].

At Likoaeng in the highlands of Lesotho (Fig. 1), excavations in the 1990s uncovered remains in Layer 1 of domestic sheep and cattle, a few fragments of iron and a single decorated EIA potsherd from a context securely radiocarbon dated (on bone, charcoal and iron) to the second half of the first millennium AD (Table 1)[18]. Other aspects of the assemblage suggest that this was otherwise an exclusively hunter-gatherer site, comparable to others known in the region. The rest of the pottery, for example, falls into a class of thin-walled (mean thickness ~6–8 mm), almost invariably grey to black, grit-tempered and undecorated ceramics found in multiple hunter-gatherer contexts elsewhere in highland Lesotho and across the uKhahlamba-Drakensberg Escarpment in KwaZulu-Natal and the Eastern Cape

Province[19,20]. Associated stone and bone artefacts, which include scrapers, adzes and arrowpoint/linkshaft fragments, are also typical of such sites and fall within the well-known Final Later Stone Age (post-classic Wilton) complex[21-24]. Contemporary EIA pottery, on the other hand, is thick-walled (mean thickness >10 mm), often decorated, and generally oxidised, rather than reduced, characteristics only matched by the one EIA sherd already mentioned[3]. Collectively, this evidence suggested contact between highland hunter-gatherers and agropastoralists in the lowlands of KwaZulu-Natal on a scale sufficient to account for the presence of domestic livestock within the Senqu Valley, a millennium or more before they are otherwise attested there. Isolated events such as raiding, trade or even hunter-gatherer care for agropastoralists' livestock were deemed unlikely given the distance to the nearest known EIA village (>150 km over rugged terrain), the ready availability of pasture within KwaZulu-Natal and the 3000-m high barrier of the uKhahlamba-Drakensberg Escarpment that intervenes between it and Likoaeng (Fig. 1a)[21,23]. It was therefore suggested that the Layer 1 assemblage might support the 'hunters-with-sheep' hypothesis previously proposed by Sadr[25,26] with respect to the Western Cape Province of southern Africa whereby some hunter-gatherer groups successfully acquired livestock from food-producers and incorporated them as ancillary resources into their own subsistence strategies.

Likoaeng is not alone in its evidence for contact between Maloti-Drakensberg hunter-gatherers and agropastoralists. A domestic sheep mandible excavated from Melikane, 40 km south of Likoaeng (Fig. 1a), is stratigraphically associated with a date of cal AD 545 – 656 (95.4% probability: Pta-1364: 1450 ± 40 BP)[32]. Much closer to Likoaeng (Fig. 1b), two rockshelters — Sehonghong[33] and the nearby site of Pitsaneng[34] — have both produced faunal remains identified as domestic sheep and cattle in layers dating to the first and second millennia AD, implying that hunter-gatherer possession of livestock may have been a recurrent, rather than a temporally isolated, phenomenon[35]. The story remains contentious however, with recently published archaeogenetic studies arguing that the presence of domestic species

in hunter-gatherer contexts in southern Africa has been over-estimated[27,36,37]. At both Blydefontein in South Africa's Eastern Cape Province and at Sehonghong in Lesotho, analysis of the ancient DNA of faunal remains morphologically identified as domestic species has instead identified the genetic signatures of wild species, leading to the conclusion that previous morphological analyses are incorrect[27,36,37]. Although these claims have been refuted by the zooarchaeologist involved in the original analysis[38], debate over the relative merits of morphological analysis *versus* molecular analysis continues[39-42]. Thus far, however, there has been no biochemical evidence to support the long-term exploitation of domestic species by hunter-gatherer groups in the Lesotho highlands.

In recent decades, lipid residue analysis of archaeological pottery has become a core tool for exploring ancient diet. Gas chromatography (GC), GC-mass spectrometry (GC-MS) and compound-specific stable carbon isotope analysis allow differentiation between ruminant (e.g. cattle, sheep and goats) and non-ruminant (e.g. pigs) adipose fats. Crucially, using this approach, ruminant dairy fats can be distinguished from the carcass fats due to biosynthetic differences between the major fatty acids[43-47]. This technique has proven pivotal for tracing the spread of dairying practices across Europe[44,48-55], the Levant[56,57], Central Asia[58] and northern[59,60] and eastern[61,62] Africa. Increasingly high sensitivity mass spectrometry has further allowed the identification of a suite of diagnostic aquatic biomarkers which may be preserved in absorbed lipid residues, including dihydroxy acids (DHYA), ω-(*o*-alkylphenyl)alkanoic acids (APAAs) and isoprenoid fatty acids (IFAs)[63]. Recent advances in the direct radiocarbon dating of individual lipid compounds extracted from archaeological pottery now provide the potential to gain crucial chronological context for the interpretation of ancient diet[62,64,65].

Lipid residue analysis of hunter-gatherer pottery excavated from Likoaeng and Sehonghong and agropastoralist ceramics from the surface of a nearby abandoned Basotho village was undertaken to explore the diet of these groups after the arrival of agropastoralists in adjacent parts of southern Africa

from the early centuries AD. The specific aim was to determine if there was any evidence for contact with agropastoralist groups through the subsistence strategies of highland hunter-gatherers. The results hold important implications for understanding the interactions between, and practices of, indigenous and incoming groups since the arrival of agriculture in south-eastern Africa in the first millennium AD.

Results

Lipid preservation and distribution

Thirty potsherds from Likoaeng (Layer 1), 17 from Sehonghong (eight from Layer GAP, nine from Layer DC) and 27 from the Basotho village Mokatlapoli were analysed in the study (Extended Data Fig. 1). Lipid preservation was excellent at all three sites. Likoaeng had an average yield of 0.4 mg lipid per gram of potsherd (g^{-1}) with 87% of sherds (*n*=27) yielding sufficiently high lipid concentrations for analysis via gas chromatography – combustion – isotope ratio mass spectrometry (GC-C-IRMS) (Supplementary Table 1). The high rate of preservation at Likoaeng is comparable with sites in the hyper-arid conditions of North Africa[59]. At Sehonghong, 41% of potsherds (*n*=7) contained sufficient lipids for isotopic analysis (five from Layer DC, two from Layer GAP; Supplementary Table 2), while at Mokatlapoli 41% (*n*=11) did so (Supplementary Table 3). One exceptional sherd from Sehonghong Layer DC contained > 10mg g^{-1}. Excluding this outlier, the average lipid yield from Sehonghong was 0.5 mg g^{-1}, whereas that from Mokatlapoli was 0.3 mg g^{-1}. The composition of the majority of lipid extracts resembled degraded animal fats (Fig. 2), dominated by $C_{16:0}$ and $C_{18:0}$ fatty acids although five residues from the historic site of Mokatlapoli and one from Layer GAP at Sehonghong contained high intensities of unsaturated fatty acids, possibly deriving from plant-based oils[66]. Only the animal-derived fats are considered further here.

Compound specific stable isotopic values

The compound-specific stable carbon isotope values of lipid residues extracted from pottery from Likoaeng, Sehonghong and Mokatlapoli are shown in Fig. 3 (Supplementary Tables 1-3). The $C_{16:0}$ and $C_{18:0}$ fatty acids exhibited a wide range of $\delta^{13}C$ values, from -30‰ to -13‰ (Fig. 3a). To allow comparison of lipid residues derived from mixed C_3/C_4 sources the results are compared using the globally applicable $\Delta^{13}C$ proxy ($\delta^{13}C_{18:0}$ - $\delta^{13}C_{16:0}$ plotted against $\delta^{13}C_{16:0}$; Fig. 3b), which emphasises metabolic origins of fats over environmental variability[48,59,67,68]. From Layer 1 at Likoaeng, 10 of the lipid extracts exhibited $\delta^{13}C_{18:0}$ and $\delta^{13}C_{16:0}$ values characteristic of ruminant dairy fats, 10 those of ruminant adipose fats and seven those of non-ruminant adipose fats. The single animal fat residue from Layer GAP at Sehonghong had an isotopic composition characteristic of ruminant adipose fat whereas two of the lipid extracts from Layer DC had $\delta^{13}C_{18:0}$ and $\delta^{13}C_{16:0}$ values characteristic of dairy fats and three of ruminant adipose fats. At Mokatlapoli, five of the degraded animal fats derived from dairy products and one sits on the border between dairy and ruminant adipose fat. Due to the low content of $C_{18:0}$ fatty acids in aquatic fats, the mixing of these with terrestrial adipose fats can lead to more negative $\Delta^{13}C$ values[69]. A theoretical mixing model based on the data obtained in this study indicates that such mixtures would not produce $\Delta^{13}C$ values reaching the range of ruminant dairy fats and would be far removed from the very negative $\Delta^{13}C$ values obtained for the dairy residues at all three sites (Supplementary Fig. 1). Moreover, biomarkers for aquatic fats were infrequent amongst those residues classified as dairy fats.

Aquatic biomarkers

An aquatic contribution was determined in 10 potsherds from Likoaeng, based upon the presence of long chain ($C_{20:0}$ and $C_{22:0}$) APAAs (Fig. 2b) and two or more isoprenoid fatty acids (IFAs; Fig. 3; Supplementary Table 1). In a further six residues, the identification of only $C_{18:0}$ – $C_{20:0}$ APAAs and one IFA means that an aquatic contribution is likely but not certain (Supplementary Table 1; marked as 'Likoaeng - aquatic?' in Fig. 3). The aquatic biomarkers were identified in residues characterised isotopically as

deriving predominantly from ruminant adipose products (n = 6), as well as non-ruminants (which would include fish) (n = 2) and dairy (n = 2), implying that the pots were used for processing both aquatic and terrestrial fats. The relatively low proportion of $C_{18:0}$ fatty acid in aquatic fats means that the stable isotopic values obtained from such mixtures will be strongly biased towards the terrestrial species[69]. In contrast, at Sehonghong aquatic biomarkers were recovered from possibly only one residue (SHH41), classified as predominantly of dairy origin, and no aquatic biomarkers at all were recovered from residues from Mokatlapoli (Supplementary Tables 2; 3).

Direct dating of dairy residues in pottery

To confirm the antiquity of the pottery and its dairy contents, we conducted compound-specific radiocarbon dating of the absorbed fatty acids from two sherds[62,64,65,71,72]. Sherds LIK10 and SHH42 (Extended Data Fig. 1), containing high concentrations of saturated $C_{16:0}$ and $C_{18:0}$ fatty acids and shown through compound-specific stable carbon isotope analysis to derive from a dairy origin, were selected and individual fatty acids collected using preparative-GC and radiocarbon dated (Supplementary Table 4). The radiocarbon dates from these residues calibrate to cal AD 579 – 654 (95% probability; BRAMS-2613: 1481 ± 27 BP) for LIK10 (combined date) and cal AD 885 – 990 (95% probability; BRAMS-2612: 1161± 28 BP) for SHH42 (combined date). They confirm that the dairy residues, and thus the pottery vessels from which they derive, date to the mid- and late-first millennium AD at Likoaeng and Sehonghong respectively (Fig. 4).

Discussion

The biomolecular analysis of residues extracted from potsherds from Likoaeng and Sehonghong, which include two directly dated examples, provides strong evidence for the exploitation of domesticated secondary products by hunter-gatherer groups in the highlands of Lesotho in the mid-/late-first

millennium AD, with dairy residues comprising *ca.* 35% of residues characterised (n=12). The direct date from the dairy residue LIK10 from Likoaeng (cal AD 579-654 at 95.4% probability; BRAMS-2613: 1481 ± 27 BP) is within 2σ of the dated charcoal from the same layer (cal AD 641–969 at 95.4% probability; Pta-7877: 1310 ± 80 BP) although the precision of the charcoal date is rather low. The dairy residue dates slightly older than the bone (cal AD 681–884 at 95.4% probability; GrA-23237: 1285 ± 40 BP) and iron (cal AD 682–879 at 95.4% probability; GrA-26831: 1290 ± 30 BP) dates from Layer 1, possibly indicating a longer span of occupation represented in the layer than the existing dates suggested. Based upon archaeological interpretation and five existing radiocarbon dates (Table 1), Layer DC at Sehonghong was thought to have accumulated during occupation of the site during both the first and second millennia AD, but the clustering of radiocarbon dates indicates that the bulk of material originates from the late first millennium AD. The direct date we obtained from the dairy residue SHH42 (cal AD 885-990 at 95.4% probability; BRAMS-2612: 1161 ± 28 BP) is consistent with this earlier cluster, confirming that dairying was practised here from the earliest phase of this occupation layer. In the late nineteenth/early twentieth centuries at nearby Mokatlapoli nearly all of the animal-derived pottery lipid residues derive from dairy products (ΔC_{18}-$C_{16} \leq$ -3.1‰; one is on the border between ruminant dairy and ruminant adipose indicating mixing). This indicates that dairy products formed an important part of the subsistence strategies of both precolonial hunter-gatherers and nineteenth-/twentieth-century Basotho agriculturalists (Fig. 4). When taken in conjunction with the osteoarchaeological identification of domestic livestock in the faunal assemblages at Likoaeng[22] and Sehonghong[73], the evidence for maintenance and exploitation of domestic animals and their secondary products in the Lesotho highlands by hunter-gatherer groups is compelling.

The exploitation of dairy products confers an important adaptive advantage onto humans, providing a predictable source of carbohydrate, fat, protein and calcium, as well as liquid during times of drought, and greatly increases the degree of nutrition represented by one animal. The distinct advantages of milk

consumption led to a rapid increase in the frequency of adult humans able to digest lactose (lactase persistence), representing one of the strongest signals of positive selection observed in recent *Homo sapiens* populations, and one that occurs at highest frequencies in traditionally pastoralist populations[74-77]. Lactase persistence was likely present only in low frequencies in the hunter-gatherer groups inhabiting Likoaeng and Sehonghong in the mid-late first millennium AD. However, fermented dairy products, facilitated by the use of pottery, retain their nutritional value[78] and are much more palatable for lactose intolerant individuals compared to fresh milk, largely due to the hydrolysation of lactose to its component sugars during the fermentation process[79]. It is probable that the dairy residues recovered during this study originate from fermented milk products, which permit the consumption of secondary products by lactose intolerant individuals without detrimental health effects. Fermented milk is still widely consumed in Lesotho ('mafi') and South Africa ('amasi') today[80].

The high variety of animal taxa present at Likoaeng and Sehonghong indicates that a wide range of resources was exploited by the hunter-gatherer groups who occupied these sites in the first and second millennia AD[22,33,73]. Whereas dairy residues most likely derive from domestic species, such as sheep, goats or cattle, the ruminant carcass fats could originate from either domesticates or hunted antelope including common duiker (*Sylvicapra grimmia*), grey rhebuck (*Pelea capreolus*), mountain reedbuck (*Redunca fulvorofula*), red hartebeest (*Alcelaphus buselaphus*) and eland (*Taurotragus oryx*). The non-ruminant carcass residues, on the other hand, most likely derive from fish (at both sites), or, at Sehonghong in particular, mammals such as rock hyrax (*Procavia capensis*), scrub hare (*Lepus saxatilis*), warthog (*Phachochoerus africanus*) and baboon (*Papio hamadryas*).

Whilst the stable carbon isotopic composition of wild animals reflects their preferred pasture, that of domestic species will reflect an average of the different pastures they are exposed to by the groups managing them. Although the environmental composition of Layer 1 at Likoaeng predominantly

consisted of C_4 grassland (*ca.* 70%)[81], both aspect and elevation significantly affect the C_3/C_4 composition. Only relatively short-distance movements of no more than 5–15 km from both Likoaeng and Sehonghong (readily achieved by following rivers upstream from these sites) would reach elevations where the vegetation cover becomes predominantly C_3 (2100–2700 m a.s.l. depending on aspect)[82].

The $\delta^{13}C_{16:0}$ and $\delta^{13}C_{18:0}$ values of the dairy residues from Likoaeng are lower than the ruminant/non-ruminant carcass fats from the same site (Fig. 3), indicating a greater C_3 contribution to the dairy fats. This could reflect the preferential grazing of domesticates (predominantly exploited for milk) at elevated C_3 pastures whereas the mixed C_3/C_4 signal of the carcass fats could represent the preferred pastures of hunted wild game or be a reflection of the integrated signature of carcass tissues from domestic animals moved seasonally between C_3 and C_4 pastures. The practice of vertical transhumance is well attested in Lesotho historically[83] and continues today. Traditionally, livestock would be kept in the village environs throughout winter and moved to better grazing at higher elevations for the summer months[84], a period when milk production is highest. The isotopic patterning of the dairy residues observed at Likoaeng, directly dated to the first millennium AD, suggests that a mobile system of animal management was also practised by the population occupying that site during that time.

A striking isotopic separation (*ca.* 5 - 6‰) can also be observed in the dairy residues between the late first-millennium hunter-gatherer sites and the historic Basotho agropastoralist village (Fig. 3), which is located in close proximity to the site of Sehonghong. The dairy residues from Mokatlapoli have a clear C_4 isotopic signal. Considering the 1000 year time gap between these observations, the wide isotopic separation in the dairy residues likely reflects differences in animal husbandry practices. Historically and today, cattle are grazed on maize stubble after crops are harvested[84] (P. Mitchell, pers. obs.), which would increase the C_4 signal in the diet of domesticates after its introduction in the nineteenth century and explain the shift in the isotopic composition of domesticate tissues.

239 Fish remains represent just under 20% of the faunal collection of Layer 1 at Likoaeng[22]. Due to the site's
240 location on the bank of the Senqu River, the presence of aquatic fats in potsherds from Likoaeng is
241 unsurprising. Indeed, a rock art scene immediately adjacent to the site depicts the use of what are
242 probably basket traps and fences to catch fish migrating up the Senqu, although its age is unknown[85].
243 The Sehonghong sequence likewise documents a long history of exploitation of fish, with fish forming a
244 large portion of the faunal assemblage from Layers GAP and DC[73]. The presence of partial suites of
245 aquatic biomarkers in potsherds from Likoaeng further attests to the exploitation of aquatic resources
246 by people inhabiting the sites. Consistent with the fact that Basotho largely ignored fish as a source of
247 food in precolonial times[86,87], aquatic biomarkers are absent from the potsherds from Mokatlapoli.

248 The decoration on the single EIA potsherd from Likoaeng indicates that it belongs to either the Msuluzi
249 (AD 650–750), or Ndondonwane (AD 750–950), phase of the Kalundu Tradition of the Early Iron Age[21],
250 both of which are well-represented at farming villages in KwaZulu-Natal[3]. Work by Maggs[88] and Mazel[89]
251 in KwaZulu-Natal's Thukela Basin region immediately northeast of the uKhahlamba-Drakensberg
252 Escarpment has uncovered extensive evidence for contact between hunter-gatherers and incoming
253 agricultural populations in the first millennium AD. The agricultural settlement of Msuluzi Confluence,
254 for example, appears to have produced iron in excess of local demand, leading Maggs[88] to suggest that
255 this was likely for exchange with non-iron-producing hunter-gatherer groups. The iron fragments
256 recovered at Likoaeng must also come from this kind of source.

257 Existing networks of exchange between hunter-gatherer groups living on both sides of the uKhahlamba-
258 Drakensberg Escarpment may have facilitated the easy spread of such commodities, but the presence of
259 dairy residues in potsherds at both Likoaeng and Sehonghong suggests that those making and using the
260 ceramics from which they came had sufficient knowledge of animal husbandry to exploit the secondary
261 products of cattle and/or caprines. Moreover, the fact that – except for the single decorated EIA sherd

from Likoaeng – all the pottery analysed there and from Layers DC and GAP at Sehonghong is of hunter-gatherer type[19,20] strongly suggests that those dairy residues derive from livestock living in or very close to the Senqu Valley. Although these animals, or their ancestors, must originally have been obtained from an agropastoralist source, there is absolutely no archaeological or historical evidence to indicate that agropastoralists were living in highland Lesotho prior to 1878. Had they been, they would, for example, undoubtedly have been recognised when Joseph Orpen and James Murray Grant led a British military expedition through the region, stopping off at Sehonghong, in 1873[90,91]. The absence of agropastoralists and the otherwise entirely Later Stone Age context of the pottery from both Likoaeng and Sehonghong reinforces the argument that the ceramics we have analysed are indeed of hunter-gatherer origin.

Although the numbers of livestock identified as being present at Sehonghong[73] have been questioned, Horsburgh, et al.[27] confirmed the presence of one *Bos taurus* specimen (SHH-7358) in Layer DC at Sehonghong. Unfortunately, the 1.8 g bone fragment was consumed during aDNA analysis so direct dating of the specimen was not possible. The bone came from the same square and context as a distal phalanx (SHH-7356) that Horsburgh, et al.[27] identified as eland (rather than cattle) and directly dated to cal AD 775–983 (95% probability; Wk-34784: 1200 ± 30 BP). This may indicate that it is of similar age but associated dates must be treated with caution. Although this result does provide molecular support for the small-scale presence of domestic livestock at Sehonghong, the presence of a single donkey (*Equus asinus*) specimen in Layer GAP and of several pig (*Sus scrofa*) and chicken (*Gallus gallus*) specimens in Layer DC shows that some disturbance of the uppermost levels of Sehonghong's stratigraphy has taken place; none of these species can have been available locally before the onset of Basotho settlement in 1878[73]. However, the direct dating of a dairy residue from Sehonghong now confirms the antiquity of domesticates at this site.

Although molecular analysis of the Likoaeng domestic assemblage has not yet been undertaken, the reliability of the identification of sheep remains at Likoaeng has specifically been questioned based on the aDNA results obtained at Sehonghong[37]. From the faunal collection at Likoaeng, nine specimens were morphologically attributed to sheep/goat, two to sheep (*Ovis aries*) and eight to cattle (*Bos taurus*)[23]. Most of these were recovered from Layer 1, with just a few small elements displaced downwards below this[23]. Although collagen from the cattle bones was insufficiently preserved for dating, direct AMS dating of one sheep/goat bone confirms the antiquity of this specimen and produced a result (cal AD 681–884 at 95% probability; GrA-23237: 1285 ± 40 BP) consistent with the remainder of the chronological evidence for Layer 1[23]. The directly dated dairy residue from Likoaeng (cal AD 600-644 at 95% probability; BRAMS-2613: 1481 ± 27 BP) clearly attests to the presence of domestic livestock at the site in the first millennium AD. It does not, however, tell us the number of animals that were present. The high calorific value of milk means that dairy products could have formed an important supplement to the diet even at very low numbers of livestock or in situations where few such animals were killed and the rest kept as socio-political capital and/or for dairy production[92].

Conclusion

The results reported here provide further evidence that by the late first millennium AD hunter-gatherer communities living in the highlands of eastern Lesotho had established contact with agropastoralist communities, most likely ones located in lowland areas of KwaZulu-Natal over 150 km away. The presence of dairy residues in otherwise Later Stone Age contexts at both Sehonghong and, more compellingly, Likoaeng supports the notion of hunter-gatherer people practising a 'hunters-with-sheep' form of subsistence[25]. This directly dated evidence lends support to the argument that such contacts, and the incorporation of caprines and cattle, were a feature of people living in highland Lesotho during

the late first millennium AD. This suggests that only a few centuries after the establishment of EIA agropastoralist communities in KwaZulu-Natal, such contacts were sufficiently close to allow for the successful transfer to Maloti-Drakensberg hunter-gatherers of both domestic livestock and of the knowledge required to look after them. Patterning in the isotopic values of the residues reveals likely differences in animal management strategies between then and recent times, as evidenced by the C_4 animal signatures from the late nineteenth-/early twentieth-century agropastoralist settlement at Mokatlapoli, likely deriving from foddering on more recently-introduced crops including maize and sorghum.

The ongoing debate surrounding the relative merits of osteoarchaeological versus molecular analyses for correctly identifying the presence of domestic livestock in faunal assemblages from archaeological sites[27,36-41] attests to the importance of investigating such wide-reaching questions via multiple lines of enquiry. Considering the high level of lipid residue preservation at these southern African sites, this type of analysis has an important part to play in the ongoing debate surrounding the introduction of livestock-keeping into the region. Since direct dating of faunal remains from the area has been hampered by poor collagen preservation[23,27], the direct dating of fatty acids of dairy origin extracted from the potsherds provides an important alternative approach[62,64,65]. Osteoarchaeological identification is clearly a practice that may at times deliver faulty results (for example, the proximal radius from Sehonghong morphologically identified as sheep[73], but directly dated to 5870 ± 30 BP (Wk-34787), several millennia before any domestic livestock were present in southern Africa[27]). However, it cannot be assumed that ancient DNA identifications are without difficulties of their own, especially where, as in highland Lesotho[27], organic preservation is poor. Both approaches would likely benefit from blind-testing and comparative analysis by more than a single specialist or laboratory, following the examples of radiocarbon dating or microwear and residue analyses of stone tools. In the meantime, our biomolecular analysis and direct dating of fatty acid residues from hunter-gatherer ceramics at

Sehonghong and Likoaeng not only provide an independent line of evidence to address this debate, but also suggest that, on the whole, the osteoarchaeological identifications previously reported there[22,73] are likely to be correct.

Materials and methods

Sites and samples

Likoaeng (29°44”S, 28°45”E; 1725 metres above sea level (m a.s.l.)) is located in the Senqu Valley in the Thaba Tseka District of Lesotho. It is an open-air campsite on the southern side of the confluence of a stream (of the same name) with the western bank of the Senqu (Orange) River (Fig. 1b; Extended Data Fig. 2). Eighteen radiocarbon dates set the duration of human activity from 3700–1100 BP. The uppermost occupation horizon (Layer 1) (located under approximately 0.2–1.5 m of culturally sterile sediment; Extended Data Fig. 3) is dated by three radiocarbon determinations to cal AD 641–969 (Table 1), consistent with the age of the one decorated sherd recovered which belongs to the Msuluzi or, more likely, Ndondonwane phase of the Early Iron Age[3]. Layer 1 was the only excavated context at Likoaeng to contain pottery. In their thin walls (mean = 7.6 ± 9.5 mm thick, *n*=80), grit temper, largely grey colour and lack of decoration, 77 of the remaining 79 potsherds recovered are typical of the ceramics found at other hunter-gatherer sites in highland Lesotho[28,32,34], KwaZulu-Natal[19] and the Eastern Cape Province[93]. Such pottery continued to be made locally into the late nineteenth century[94-96], while sources of clay were exploited by Basotho residents of the area into the early 1900s (Chris Wingfield, pers. comm.). Thirty of these sherds, along with the decorated EIA sherd, were selected for analysis (Extended Data Fig. 1). Two conjoining red-coloured sherds with exceptionally thin walls and highly burnished exteriors complete the ceramic assemblage from Likoaeng Layer 1, but cannot readily be paralleled elsewhere in

354 the region, except perhaps at Good Hope Shelter in the uKhahlamba-Drakensberg Escarpment of
355 KwaZulu-Natal[97]. Neither was analysed in this study.

356 Sehonghong rockshelter (29°46”S, 28°47”E, 1750 m a.s.l.; Extended Data Fig. 4) lies 3 km south-east of
357 Likoaeng, on the south-eastern bank of the Sehonghong River, which meets the Senqu River 3 km
358 further downstream (Fig. 1b). Sehonghong was first occupied in the Middle Stone Age and preserves a
359 series of occupation pulses across Marine Isotope Stages 3 and 2 as well as the Holocene[98,99]. Oral
360 histories indicate that it was an important hunter-gatherer base as late as *ca.* 1870 and that the last San
361 individuals to live there did so as recently as *ca.* 1902[96,100]. Pottery attributable to Maloti-Drakensberg
362 hunter-gatherers by virtue of its thin walls (mean thickness = 7.8 ± 1.6 mm, *n*=268), overwhelmingly
363 reduced condition (grey/black colour), grit temper and lack of decoration (except for rare instances of
364 burnishing) was recovered from the uppermost three layers (Extended Data Fig. 5)[28]. Layer SS (Surface
365 Scrapings) is a loose grey brown dust that forms the modern surface of the site. Underneath this, Layer
366 DC (Dung Crust) is a hard friable layer rich in bovine and equine dung that becomes finer and ashier
367 towards the bottom. This layer includes the material culture of the hunter-gatherers who made use of
368 the site in the late first and second millennia AD[28], but the consistency of radiocarbon dates from it
369 recently obtained by Horsburgh et al.[27] raises the possibility that much of its content dates to the late
370 first millennium AD and might therefore be close in age to Layer 1 at Likoaeng. Underlying DC, Layer GAP
371 accumulated in the first half of the first millennium AD and is a soft, loose, grey charcoal-rich ashy layer.
372 In total, eight sherds were analysed from GAP and nine from DC.

373 During field survey of the area around Sehonghong in 1992 an open-air stone artefact scatter
374 (2928DB38) was identified 2 km upstream of the site close to a small cluster of abandoned stone-walled
375 houses with adjacent stock enclosures (29˚44”S, 28˚48”E). Although no enquiries were made at the time
376 regarding the history of this site or of the nearby village of Masakoane, a settlement by the name of

Mokatlapudi (Mokatlapoli in correct Sesotho spelling) appears just to the west of Masakoane on the map of Lesotho prepared by Captain M.C. Dobson[101] between 1904 and 1909. This village was described as "now stated in ruins" in 1950 in Webb's[102] *Gazetteer of Basutoland*. It seems very plausible that the ruins near 2928DB38 therefore belong to Mokatlapoli (Fig. 1b). Webb's observation, coupled with the fact that there was no Basotho settlement anywhere in the Sehonghong or broader Upper Senqu region before 1878, narrows the age of the ceramics retrieved from the surface of Mokatlapoli to the last two decades of the nineteenth and first four decades of the twentieth centuries. This pottery differs from that recovered from Likoaeng and Sehonghong in being thicker (mean thickness = 10.5 ± 3.7 mm, *n*=69), predominantly orange or buff (rather than grey to black) in colour and not infrequently burnished[28]. Twenty-seven of these sherds were analysed in order to obtain a set of residue results for comparison with the hunter-gatherer pottery from Sehonghong and Likoaeng.

Lipid extraction

Potsherds were cleaned of exogenous lipids by removing the outer surface (*ca.* 2 mm) using a Dremel drill. 1-3 g of potsherd was sampled and ground to a fine powder in a solvent-washed glass mortar and pestle. Lipids were simultaneously extracted and methylated using established methods (4% v/v H_2SO_4/MeOH, 5 mL, 70 °C, 1h)[103]. Analytical blanks were prepared alongside each batch of 10 sherds to monitor laboratory-based contamination. The same extraction method repeated three times on new powdered clay (up to 5 g) was followed for the radiocarbon analyses of lipid residues.

Instrumental analysis

Samples were analysed on an Agilent 7890A GC fitted with an on-column injector, flame ionisation detector and a non-polar high temperature DB1-HT column (stationary phase 100% dimethylpolysiloxane, 0.32 mm internal diameter, 0.1 µm film thickness) using helium as a carrier gas (1

µl injection volume). The temperature program consisted of a 1 min isothermal at 50 °C, increasing to 350 °C (5 min isothermal) at 25 °C min^{-1}.

For analysis via GC-MS, fatty acid methyl esters (FAMEs) were initially analysed using a ThermoFinnigan Trace mass spectrometer fitted with a non-polar column (100% dimethylpolysiloxane, length 50 m, internal diameter of 0.32 mm and film thickness of 0.17 µm) in EI mode, scanning from m/z 50 – 650 (electron energy 70 eV, scan time of 0.6 s). The temperature program commenced at 50 °C (1 min) increasing at 10 °C min^{-1} until 300°C (10 min isothermal). The FAMEs were re-analysed using a ThermoFinnigan single quadrupole TraceMS in EI mode (electron energy 70 eV) fitted with a fused silica capillary column with a high cyano-modified cyanopropyl polysilphenylenesiloxane stationary phase (Agilent J & W, VF-23ms, 60 m x 0.32 mm i.d., 0.15 µm film thickness). The oven temperature programme comprised an isothermal at 70 °C, ramping to 100 °C at 10 °C min^{-1} and a second ramp to 250 °C at 4 °C min^{-1}. The GC/MS was operated in both full scan (*m/z* 50 – 650) and selected ion monitoring (*m/z* 105, 262, 290, 318 and 346) mode for the identification of aquatic biomarkers (APAAs and IFAs). Data were collected and analysed using Xcalibur software (v. 2.0) and a NIST spectral database.

The $\delta^{13}C$ values of the $C_{16:0}$ and $C_{18:0}$ fatty acids were obtained using an Agilent 7890A GC fitted to an Isoprime isotope ratio mass spectrometer (IRMS). The temperature program began at 40 °C (2 min), increasing by 10 °C min^{-1} to reach 300 °C (10 min isothermal). Samples were run in duplicate; final results are an average taken of the two values. Analytical reproducibility was ±0.4‰. Instrumental error was ±0.2‰. The isotopic values were corrected to account for the carbon atoms added during the methanolic extraction according to Rieley[104]. The $\delta^{13}C$ values were derived according to the equation: $\delta^{13}C‰ = ((R_{sample}-R_{standard})/R_{standard}) \times 1000$ (relative to the international standard Pee Dee Belemnite (PDB) and where $R=^{13}C/^{12}C$).

For ^{14}C dating, the $C_{16:0}$ and $C_{18:0}$ fatty acids were isolated by preparative capillary GC (pcGC) on an Hewlett-Packard 5890 series II GC coupled to a Gerstel preparative fraction collector (PFC) following recently established procedures[64,65,105]. Total lipid extracts (TLEs) concentrated at *ca*. 5 $\mu g.\mu L^{-1}$ were injected 40 times into a Rxi-1ms (DB1, 30mx 0.53 mm i.d., 1.5 µm film thickness) column and the fatty acids were collected in a solvent-less trapping system (STS). He (10 psi) was used as carrier gas. The GC oven started with an isothermal hold at 50 °C for 2 min, increased to 200 °C at 40 $°C.min^{-1}$, then increased to 270 °C at 10 $°C.min^{-1}$ and finally increased to 300 °C at 20 $°C.min^{-1}$ and held for 8.75 min. Procedural blanks and standard consisted of trapping sequences of *n*-hexane mirroring the one of FAMEs, then addition of the radiocarbon standards (IAEA C7, Phtalic anhydride) to the traps content. The isolated compounds were combusted and graphitised in a Vario Microcube Elemental Analyser coupled with an Automated Graphitization Equipment (EA-AGE3)[106]. Graphite targets were pressed using a Pneumatic Sample Press and analysed on the BRIS-MICADAS accelerator mass spectrometer of the Bristol Radiocarbon Accelerator Mass Spectrometry (BRAMS) facility alongside radiocarbon and processed standards (OXA II, IAEA C7, phthalic anhydride). Correction of the measurements for the methyl group added during the derivatization was performed using a mass balance[71]. Combination of the measurements was performed as described in Casanova, et al.[65]. Radiocarbon ages were calibrated in OxCal 4.3[31] against the southern hemisphere, SHCal13, calibration curve[30].

Data availability

All data generated or analysed during this study are included in this published article and its supplementary information files.

References

1 Mitchell, P. J. *The Archaeology of Southern Africa*. (Cambridge University Press, 2002).

2 Mitchell, P. J. & Whitelaw, G. The archaeology of southernmost Africa from c. 2000 BP to the early 1800s: a review of recent research. *Journal of African History* **46**, 209-241, doi:10.1017/S0021853705000770 (2005).

3 Huffman, T. N. *Handbook to the Iron Age: the Archaeology of Pre-colonial Farming Societies in Southern Africa*. (University of KwaZulu-Natal Press, 2007).

4 Gill, S. *A Short History of Lesotho*. (Morija Museum and Archives, 1993).

5 Vinnicombe, P. V. *People of the Eland: Rock Paintings of the Drakensberg Bushmen as a Reflection of their Life and Thought*. (University of Natal Press, 1976).

6 Manhire, A. H., Parkington, J. E., Mazel, A. D. & Maggs, T. M. O. C. Cattle, sheep and horses: a review of domestic animals in the rock art of southern Africa. *South African Archaeological Society Goodwin Series* **5**, 22-30, doi:10.2307/3858142 (1986).

7 Jolly, P. Melikane and Upper Mangolong revisited: the possible effects on San art of symbiotic contact between south-eastern San and southern Sotho and Nguni communities. *South African Archaeological Bulletin*, 68-80 (1995).

8 Jolly, P. Interaction between south-eastern San and southern Nguni and Sotho communities c.1400 to c.1880. *South African Historical Journal* **35**, 30-61, doi:10.1080/02582479608671246 (1996).

9 Jolly, P. The San rock painting from “The Upper Cave At Mangolong”, Lesotho. *South African Archaeological Bulletin* **61**, 68-75 (1996).

10 Jolly, P. Before farming? Cattle kept and painted by the southeastern San. *Before Farming* **4**, 1-29 (2007).

11 Louw, T. A. A preliminary survey of Khoi and San influence in Zulu. *Khoisan Linguistic Studies*, 8-21 (1979).

12 Tesele, F. T. *Symbols of power: beads and flywhisks in traditional healing in Lesotho*, University of Cape Town (1994).

13 Hammond-Tooke, W. D. Selective borrowing? The possibility of San shamanistic influence on Southern Bantu divination and healing practices. *South African Archaeological Bulletin* **53**, 9-15 (1998).

14 González-Santos, M. *et al.* Genome-wide SNP analysis of southern African populations provides new insights into the dispersal of Bantu-speaking groups. *Genome Biology and Evolution* **7**, 2560-2568, doi:10.1093/gbe/evv164 (2015).

15 Marks, S. J. *et al.* Static and moving frontiers: the genetic landscape of southern African Bantu-speaking populations. *Molecular Biology and Evolution* **32**, 29-43, doi:10.1093/molbev/msu263 (2015).

16 Schlebusch, C. M., Prins, F., Lombard, M., Jakobsson, M. & Soodyall, H. The disappearing San of southeastern Africa and their genetic affinities. *Human Genetics* **135**, 1365-1373, doi:10.1007/s00439-016-1729-8 (2016).

17 Bajić, V. *et al.* Genetic structure and sex-biased gene flow in the history of southern African populations. *American journal of physical anthropology* **167**, 656-671, doi:10.1002/ajpa.23694 (2018).

18 Mitchell, P. J., Plug, I. & Bailey, G. N. Spatial patterning at Likoaeng, an open-air hunter-gatherer campsite in the Lesotho Highlands, southern Africa. *Archaeological Papers of the American Anthropological Association* **16**, 81-94, doi:10.1525/ap3a.2006.16.1.81 (2008).

19 Mazel, A. D. Early pottery from the eastern part of southern Africa. *South African Archaeological Bulletin* **47**, 3-7 (1992).

20 Sadr, K. & Sampson, C. G. Through thick and thin: early pottery in southern Africa. *Journal of African Archaeology* **4**, 235-252 (2006).

21 Mitchell, P. J., Plug, I., Bailey, G. N. & Woodborne, S. Bringing the Kalahari debate to the mountains: late first millennium AD hunter-gatherer/farmer interaction in highland Lesotho. *Before Farming* **3**, 1-22 (2008).

22 Plug, I., Mitchell, P. J. & Bailey, G. N. Animal remains from Likoaeng, an open-air river site, and its place in the post-classic Wilton of Lesotho and eastern Free State, South Africa. *South African Journal of Science* **99**, 143-152 (2003).

23 Mitchell, P. J. *et al.* Beyond the drip-line: a high-resolution open-air Holocene hunter-gatherer sequence from highland Lesotho. *Antiquity* **85**, 1225-1242, doi:10.1017/S0003598X00062025 (2011).

24 Lombard, M. *et al.* South African and Lesotho Stone Age sequence updated (I). *South African Archaeological Bulletin* **67**, 123-144 (2012).

25 Sadr, K. The Neolithic of southern Africa. *Journal of African History* **44**, 195-209, doi:10.1017/S0021853702008393 (2003).

26 Sadr, K. Invisible herders? The archaeology of Khoekhoe pastoralists. *Southern African Humanities* **20**, 179-203 (2008).

27 Horsburgh, K. A., Moreno-Mayar, J. V. & Gosling, A. L. Revisiting the Kalahari debate in the highlands: ancient DNA provides new faunal identifications at Sehonghong, Lesotho. *Azania: Archaeological Research in Africa* **51**, 295-306, doi:10.1080/0067270X.2016.1169041 (2016).

28 Mitchell, P. J. Sehonghong: the late Holocene assemblages with pottery. *South African Archaeological Bulletin* **51**, 17-25, doi:10.2307/3888928 (1996).

29 Carter, P. L., Mitchell, P. J. & Vinnicombe, P. V. *Sehonghong: the Middle and Later Stone Age industrial sequence at a Lesotho rockshelter*. (British Archaeological Reports, 1988).

30 Hogg, A. G. *et al.* SHCal13 Southern Hemisphere calibration, 0–50,000 years cal BP. *Radiocarbon* **55**, 1889-1903, doi:10.2458/azu_js_rc.55.16783 (2013).

31 Bronk Ramsey, C. Bayesian analysis of radiocarbon dates. *Radiocarbon* **51**, 337-360 (2009).

32 Carter, P. L. *The prehistory of eastern Lesotho*, University of Cambridge, (1978).

33 Plug, I. & Mitchell, P. J. Fishing in the Lesotho highlands: 26,000 years of fish exploitation, with special reference to Sehonghong Shelter. *Journal of African Archaeology* **6**, 33-55, doi:10.3213/1612-1651-10102 (2008).

34 Hobart, J. H. Pitsaneng: evidence for a neolithic Lesotho? *Before Farming*, 1-10, doi:10.3828/bfarm.2004.4.4 (2004).

35 Mitchell, P. J. Hunter-gatherers and farmers: some implications of 1,800 years of interaction in the Maloti-Drakensberg region of Southern Africa. *Senri Ethnological Studies*, 15-46 (2009).

36 Horsburgh, K. A. & Moreno-Mayar, J. V. Molecular identification of sheep at Blydefontein Rock Shelter, South Africa. *Southern African Humanities* **27**, 65-80 (2015).

37 Horsburgh, K. A., Orton, J. & Klein, R. G. Beware the springbok in sheep's clothing: how secure are the faunal identifications upon which we build our models? *African Archaeological Review* **33**, 353-361, doi:10.1007/s10437-016-9231-1 (2016).

38 Scott, K. & Plug, I. Osteomorphology and osteometry versus aDNA in taxonomic identification of fragmentary sheep and sheep/goat bones from archaeological deposits: Blydefontein Shelter, Karoo, South Africa. *Southern African Humanities* **28**, 61-79 (2016).

39 Bousman, B. C. *et al.* The quest for evidence of domestic stock at Blydefontein Rock Shelter. *Southern African Humanities* **28**, 39-60 (2016).

40 Plug, I. Reply to Horsburgh et al. 2016: 'Revisiting the Kalahari debate in the highlands'. *Azania: Archaeological Research in Africa* **53**, 98-113, doi:10.1080/0067270X.2017.1377957 (2018).

41 Horsburgh, K., Moreno-Mayar, J. V. & Klein, R. G. Counting and miscounting sheep: genetic evidence for pervasive misclassification of wild fauna as domestic stock. *Southern African Humanities* **30**, 53-69 (2017).

42 Horsburgh, K. A. A reply to Plug: science requires self-correction. *Azania: Archaeological Research in Africa* **53**, 114-118, doi:10.1080/0067270x.2017.1387430 (2018).

43 Evershed, R. P. *et al.* New criteria for the identification of animal fats preserved in archaeological pottery. *Naturwissenschaften* **84**, 402-406 (1997).

44 Dudd, S. N. & Evershed, R. P. Direct demonstration of milk as an element of archaeological economies. *Science* **282**, 1478-1481 (1998).

45 Evershed, R. P. *et al.* Chemistry of archaeological animal fats. *Accounts of Chemical Research* **35**, 660-668, doi:10.1021/ar000200f (2002).

46 Evershed, R. P. Organic residue analysis in archaeology: the archaeological biomarker revolution *Archaeometry* **50**, 895-924, doi:10.1111/j.1475-4754.2008.00446.x (2008).

47 Roffet-Salque, M. *et al.* From the inside out: upscaling organic residue analyses of archaeological ceramics. *Journal of Archaeological Science: Reports* **16**, 627-640, doi:10.1016/j.jasrep.2016.04.005 (2017).

48 Copley, M. S. *et al.* Direct chemical evidence for widespread dairying in prehistoric Britain. *Proceedings of the National Academy of Sciences* **100**, 1524-1529, doi:10.1073/pnas.0335955100 (2003).

49 Copley, M. S., Berstan, R., Straker, V., Payne, S. & Evershed, R. P. Dairying in antiquity. II. Evidence from absorbed lipid residues dating to the British Bronze Age. *Journal of Archaeological Science* **32**, 505-521, doi:10.1016/j.jas.2004.07.005 (2005).

50 Spangenberg, J. E., Jacomet, S. & Schibler, J. Chemical analyses of organic residues in archaeological pottery from Arbon Bleiche 3, Switzerland – evidence for dairying in the late Neolithic. *Journal of Archaeological Science* **33**, 1-13, doi:10.1016/j.jas.2005.05.013 (2006).

51 Craig, O. E. *et al.* Ancient lipids reveal continuity in culinary practices across the transition to agriculture in northern Europe. *Proceedings of the National Academy of Sciences* **108**, 17910-17915, doi:10.1073/pnas.1107202108 (2011).

52 Salque, M. *et al.* Earliest evidence for cheese making in the sixth millennium BC in northern Europe. *Nature* **493**, 522-525, doi:10.1038/nature11698 (2013).

53 Cramp, L. J. E. *et al.* Immediate replacement of fishing with dairying by the earliest farmers of the Northeast Atlantic archipelagos. *Proceedings of the Royal Society B: Biological Sciences* **281**, 20132372, doi:10.1098/rspb.2013.2372 (2014).

54 Cramp, L. J. E. *et al.* Neolithic dairy farming at the extreme of agriculture in northern Europe. *Proceedings of the Royal Society B: Biological Sciences* **281**, doi:10.1098/rspb.2014.0819 (2014).

55 Craig, O. E. *et al.* Did the first farmers of central and eastern Europe produce dairy foods? *Antiquity* **79**, 882-894, doi:10.1017/S0003598X00115017 (2015).

56 Evershed, R. P. *et al.* Earliest date for milk use in the Near East and southeastern Europe linked to cattle herding. *Nature* **455**, 528-531, doi:10.1038/nature07180 (2008).

57 Gregg, M. W., Banning, E. B., Gibbs, K. & Slater, G. F. Subsistence practices and pottery use in Neolithic Jordan: molecular and isotopic evidence. *Journal of Archaeological Science* **36**, 937-946, doi:10.1016/j.jas.2008.09.009 (2009).

58 Outram, A. K. *et al.* The earliest horse harnessing and milking. *Science* **323**, 1332-1335, doi:10.1126/science.1168594 (2009).

59 Dunne, J. *et al.* First dairying in green Saharan Africa in the fifth millennium BC. *Nature* **486**, 390-394, doi:10.1038/nature11186 (2012).

60 Dunne, J., di Lernia, S., Chłodnicki, M., Kherbouche, F. & Evershed, R. P. Timing and pace of dairying inception and animal husbandry practices across Holocene North Africa. *Quaternary International* **471**, 147-159, doi:10.1016/j.quaint.2017.06.062 (2018).

61 Keute, J. Chemical analysis of fatty acid residues on archaeological pottery of pastoralist communities in northern Tanzania.in *The 81st Annual Meeting of the Society for American Archaeology.* (2016).

62 Dunne, J., Grillo, K. M., Casanova, E., Whelton, H. L. & Evershed, R. P. Pastoralist foodways recorded in organic residues from pottery vessels of modern communities in Samburu, Kenya. *Journal of Archaeological Method and Theory*, doi:10.1007/s10816-018-9384-0 (2018).

63 Cramp, L. J. E. & Evershed, R. P. in *Treatise on Geochemistry: Archaeology and Anthropology* Vol. 12 (eds H.D. Holland & K.K. Turekian) 319-339 (Elsevier, 2014).

64 Casanova, E., Knowles, T. D. J., Williams, C., Crump, M. P. & Evershed, R. P. Practical considerations in high-precision compound-specific radiocarbon analyses: eliminating the effects of solvent and sample cross-contamination on accuracy and precision. *Analytical Chemistry* **90**, 11025-11032, doi:10.1021/acs.analchem.8b02713 (2018).

65 Casanova, E. *et al.* Accurate compound-specific ^{14}C dating of archaeological pottery vessels. *Nature.* In press.

66 Woodbury, S. E., Evershed, R. P. & J., B. R. Purity assessments of major vegetable oils based on $\delta^{13}C$ values of individual fatty acids. *Journal of the American Oil Chemists' Society* **75**, 371-379, doi:10.1007/s11746-998-0055-2 (1998).

67 Evershed, R. P., Dudd, S. N., Copley, M. S. & Mutherjee, A. Identification of animal fats via compound specific $\delta^{13}C$ values of individual fatty acids: assessments of results for reference fats and lipid extracts of archaeological pottery vessels. *Documenta Praehistorica* **29**, 73-96 (2002).

68 Roffet-Salque, M., Lee, M. R. F., Timpson, A. & Evershed, R. P. Impact of modern cattle feeding practices on milk fatty acid stable carbon isotope compositions emphasise the need for caution in selecting reference animal tissues and products for archaeological investigations. *Archaeological and Anthropological Sciences* **9**, 1343-1348, doi:10.1007/s12520-016-0357-5 (2016).

69 Cramp, L. J. E. *et al.* Regional diversity in subsistence among early farmers in Southeast Europe revealed by archaeological organic residues. *Proceedings of the Royal Society B: Biological Sciences* **286**, 20182347, doi:10.1098/rspb.2018.2347 (2019).

70 Friedli, H., Lotscher, H., Oeschger, H., Siegenthaler, U. & Stauffer, B. Ice core record of the $^{13}C/^{12}C$ ratio of atmospheric CO_2 in the past two centuries. *Nature* **324**, 237-238 (1986).

71 Stott, A. W. *et al.* Direct dating of archaeological pottery by compound-specific ^{14}C analysis of preserved lipids. *Analytical Chemistry* **75**, 5037-5045, doi:10.1021/ac020743y (2003).

72 Berstan, R. *et al.* Direct dating of pottery from its organic residues: new precision using compound-specific carbon isotopes. *Antiquity* **82**, 702-713, doi:10.1017/S0003598X00097325 (2008).

73 Plug, I. & Mitchell, P. J. Sehonghong: hunter-gatherer utilization of animal resources in the highlands of Lesotho. *Annals of the Transvaal Museum* **45**, 31–53 (2008).

74 Leonardi, M., Gerbault, P., Thomas, M. G. & Burger, J. The evolution of lactase persistence in Europe. A synthesis of archaeological and genetic evidence. *International Dairy Journal* **22**, 88-97, doi:10.1016/j.idairyj.2011.10.010 (2012).

75 Gerbault, P., Roffet-Salque, M., Evershed, R. P. & Thomas, M. G. How long have adult humans been consuming milk? *IUBMB Life* **65**, 983-990, doi:10.1002/iub.1227 (2013).

76 Ranciaro, A. *et al.* Genetic Origins of Lactase Persistence and the Spread of Pastoralism in Africa. *The American Journal of Human Genetics* **94**, 496-510, doi:10.1016/j.ajhg.2014.02.009 (2014).

77 Macholdt, E., Slatkin, M., Pakendorf, B. & Stoneking, M. New insights into the history of the C-14010 lactase persistence variant in Eastern and Southern Africa. *American Journal of Physical Anthropology* **156**, 661-664 (2015).

78 Buttriss, J. Nutritional properties of fermented milk products. *International Journal of Dairy Technology* **50**, 21-27, doi:10.1111/j.1471-0307.1997.tb01731.x (1997).

79 Lomer, M. C. E., Parkes, G. C. & Sanderson, J. D. Review article: lactose intolerance in clinical practice - myths and realities. *Alimentary Pharmacology and Therapeutics* **27**, 93-103, doi:10.1111/j.1365-2036.2007.03557.x (2008).

80 Gadaga, T. H., Lehohla, M. & Ntuli, V. Traditional fermented foods of Lesotho. *The Journal of Microbiology, Biotechnology and Food Sciences* **2**, 2387-2391 (2013).

81 Parker, A. G., Lee-Thorp, J. & Mitchell, P. J. Late Holocene Neoglacial conditions from the Lesotho highlands, southern Africa: phytolith and stable carbon isotope evidence from the archaeological site of Likoaeng. *Proceedings of the Geologists' Association* **122**, 201-211, doi:10.1016/j.pgeola.2010.09.005 (2011).

82 Morris, C. Historical vegetation–environment patterns for assessing the impact of climatic change in the mountains of Lesotho. *African Journal of Range & Forage Science* **34**, 45-51, doi:10.2989/10220119.2017.1333150 (2017).

83 Ashton, H. *The Basuto*. (Oxford University Press, 1952).

84 Quinlan, T. & Morris, C. Implications of changes to the transhumance system for conservation of the mountain catchments in eastern Lesotho. *African Journal of Range & Forage Science* **11**, 76-81, doi:10.1080/10220119.1994.9647851 (1994).

85 Challis, S., Mitchell, P. J. & Orton, J. Fishing in the rain: control of rain-making and aquatic resources at a previously undescribed rock art site in Highland Lesotho. *Journal of African Archaeology* **6**, 203-218, doi:10.3213/1612-1651-10111 (2008).

86 Jacobs, N. Environment, production and social difference in the Kalahari Thornveld, c.1750-1830. *Journal of Southern African Studies* **25**, 347-373 (1999).

87 Whitelaw, G. An Iron Age fishing tale. *Southern African Humanities* **21**, 195-212 (2009).

88 Maggs, T. M. O. C. Msuluzi Confluence: a seventh century Early Iron Age site on the Tugela River. *Annals of the Natal Museum* **24**, 111-145 (1980).

89 Mazel, A. D. People making history: the last ten thousand years of hunter-gatherer communities in the Thukela Basin. *Natal Museum Journal of Humanities* **1**, 132-150 (1989).

90 Orpen, J. M. A glimpse into the mythology of the Maluti Bushmen. *Cape Monthly Magazine* **9**, 1-13 (1874).

91 Mitchell, P. J. & Challis, W. A 'first' glimpse into the Maloti Mountains: the diary of James Murray Grant's expedition of 1873-74. *Southern African Humanities* **20**, 399-461 (2008).

92 Russell, T. & Lander, F. 'What is consumed is wasted': from foraging to herding in the southern African Later Stone Age. *Azania* **50**, 267-317, doi:10.1080/0067270X.2015.1079082 (2015).

93 Opperman, H. *The Later Stone Age of the Drakensberg Range and its foothills*. (British Archaeological Reports, 1987).

94 Ellenberger, V. *La fin tragique des Bushmen*. (Amiot Dumont, 1953).

95 Mitchell, P. J. Remembering the Mountain Bushmen: observations of nineteenth century hunter-gatherers in Lesotho as recorded by Victor Ellenberger. *Southern African Field Archaeology* **15/16**, 3-11 (2006/07).

96 Vinnicombe, P. V. in *The eland's people: new perspectives in the rock art of the Maloti-Drakensberg Bushmen. Essays in memory of Patricia Vinnicombe* (eds P.J. Mitchell & B.W. Smith) 165-191 (Witwatersrand University Press, 2009).

97 Cable, J. H. C., Scott, K. & Carter, P. L. Excavations at Good Hope Shelter, Underberg District, Natal. *Annals of the Natal Museum* **24** (1980).

98 Mitchell, P. J. The late Quaternary of the Lesotho highlands, southern Africa: preliminary results and future potential of ongoing research at Sehonghong Shelter. *Quaternary International* **33**, 35-43 (1996).

99 Jacobs, Z. *et al.* Ages for the Middle Stone Age of southern Africa: implications for human behavior and dispersal. *Science* **322**, 733 (2008).

100 Mitchell, P. J. Making history at Sehonghong: Soai and the last Bushman occupants of his shelter. *Southern African Humanities* **22**, 147-168 (2010).

101 Dobson, M. C. Military report on Basutoland. (The War Office, London, 1910).

102 Webb, R. S. *Gazetteer for Basutoland*. (privately published, 1950).

103 Correa-Ascencio, M. & Evershed, R. P. High throughput screening of organic residues in archaeological potsherds using direct acidified methanol extraction. *Analytical Methods* **6**, 1330, doi:10.1039/c3ay41678j (2014).

104 Rieley, G. Derivatization of organic compounds prior to gas chromatographic–combustion–isotope ratio mass spectrometric analysis: identification of isotope fractionation processes. *The Analyst* **119**, 915-919, doi:10.1039/an9941900915 (1994).

105 Casanova, E., Knowles, T. D. J., Williams, C., Crump, M. P. & Evershed, R. P. Use of a 700 MHz NMR microcryoprobe for the identification and quantification of exogenous carbon in compounds purified by preparative capillary gas chromatography for radiocarbon determinations. *Analytical Chemistry* **89**, 7090-7098, doi:10.1021/acs.analchem.7b00987 (2017).

106 Wacker, L., Němec, M. & Bourquin, J. A revolutionary graphitisation system: fully automated, compact and simple. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* **268**, 931-934, doi:10.1016/j.nimb.2009.10.067 (2010).

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Author contributions

L.J.E.C. and P.J.M. devised the study. H.F. carried out lipid extraction and GC, GC-MS and GC-C-IRMS analyses under the supervision of L.J.E.C. E.C. carried out compound specific ^{14}C dating. All authors contributed to data analysis and interpretation. H.F. wrote the manuscript with input from all authors.

Competing interests

The authors declare no competing interests.

Figures

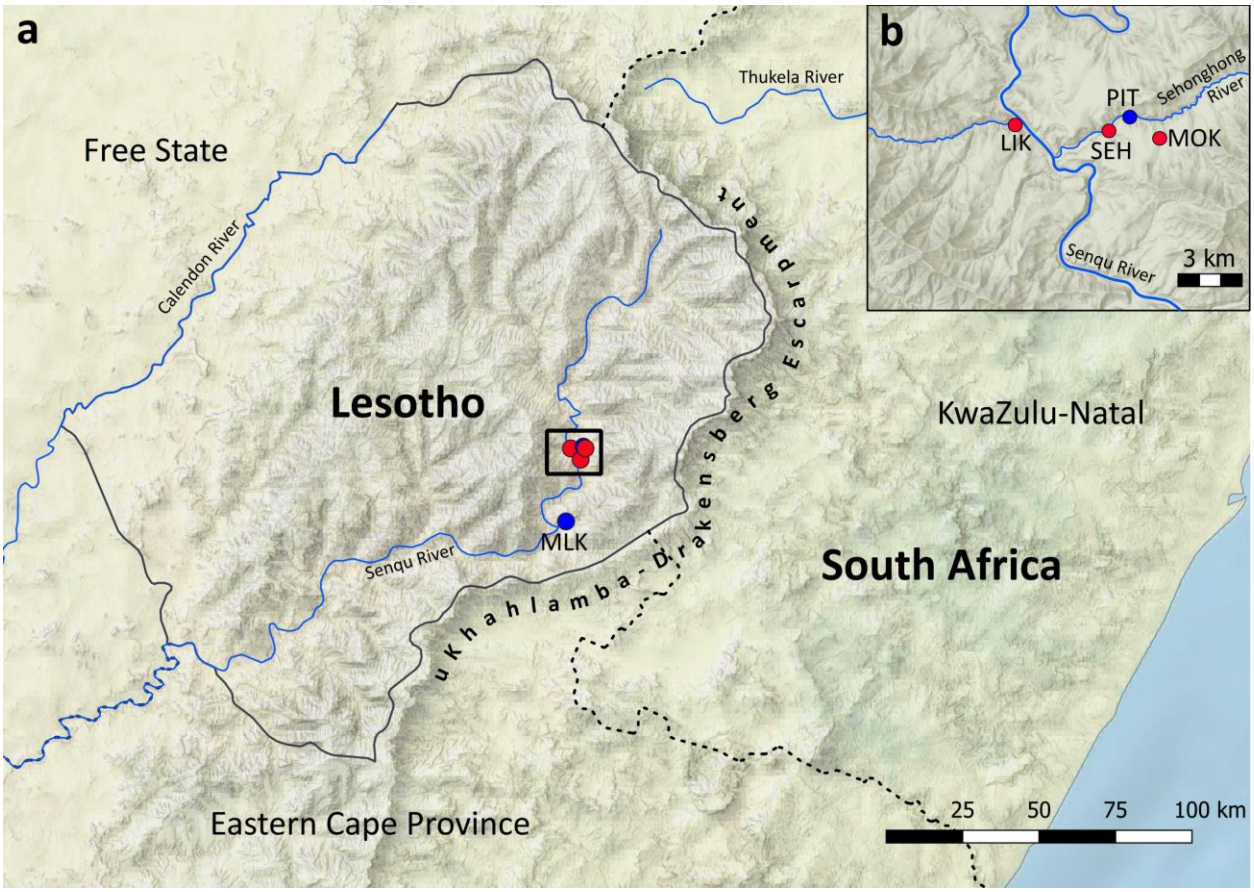
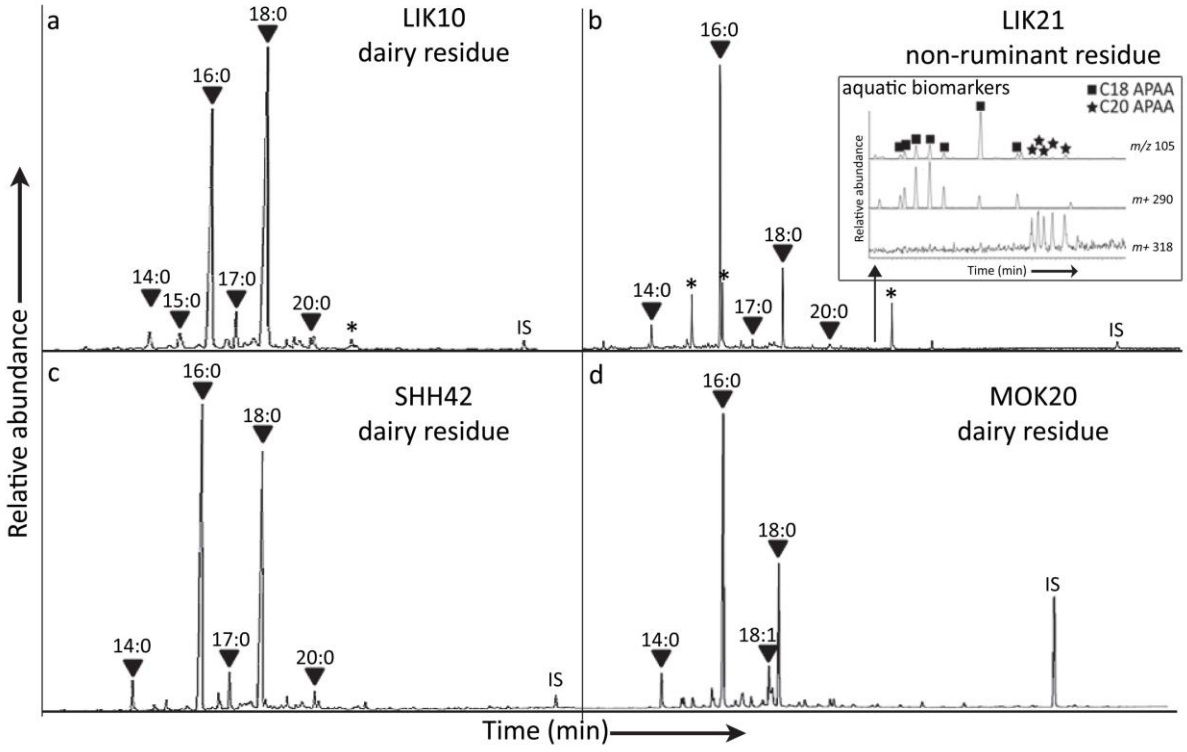


Figure 1. Map of Lesotho. a) Location of sites included in the study (red) and mentioned in the text (blue) within Lesotho, including Melikane (MLK). **b)** Close-up of the locality of Likoaeng (LIK), Sehonghong (SEH), Pitsaneng (PIT) and Mokatlapoli (MOK). (Base map downloaded from Natural Earth, free vector and raster map data available at naturalearthdata.com).



730

731 **Figure 2. Partial gas chromatograms from four extracted lipid residues with compositions**

732 **characteristic of degraded animal fats. a)** dairy residue from Likoaeng which was directly radiocarbon

733 dated; **b)** non-ruminant adipose residue from Likoaeng; inset shows mass chromatogram from same

734 residue run in SIM mode (M/z 105, M+ 290, M+ 318) identifying aquatic biomarkers $C_{18:0}$ and $C_{20:0}$

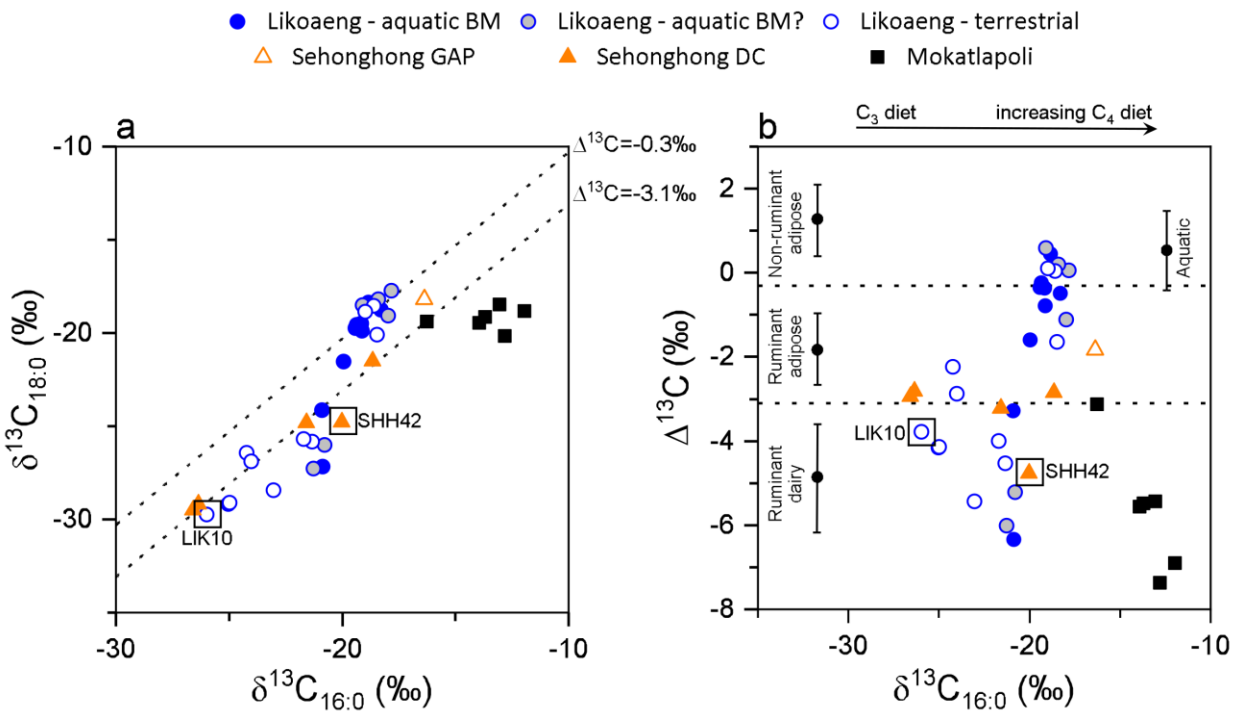
735 APAAs; **c)** dairy residue from Layer DC at Sehonghong rock shelter which was also directly radiocarbon

736 dated and **d)** dairy residue from Mokatlapoli. Peaks marked with black triangles represent individual

737 fatty acids labelled (*x*:*y*) with carbon chain length x and degree of unsaturation y. IS is the internal

738 standard (*n*-tetratriacontane). Asterisks mark phthalate peaks. Further information on the lipid

739 compositions of the remaining extracts is provided in Supplementary Tables 1-3.



740

741 **Figure 3. Compound specific stable isotopic values of degraded animal fats analysed in the study. a)**
742 $\delta^{13}C_{18:0}$ values plotted against $\delta^{13}C_{16:0}$ values and **b)** $\delta^{13}C_{18:0} - \delta^{13}C_{16:0}$ ($\Delta^{13}C$) values plotted against the
743 $\delta^{13}C_{16:0}$ values obtained from pottery organic residues with biomolecular compositions characteristic of
744 degraded animal fats from Likoaeng Layer 1, Sehonghong rock shelter from Layer GAP and Layer DC and
745 from the late nineteenth-/early twentieth-century agricultural village Mokatlapoli. The dashed lines
746 delimit the $\Delta^{13}C$ values ranges typical of dairy ($\Delta^{13}C$ < -3.1 ‰), ruminant adipose ($\Delta^{13}C$ = -3.1 ‰ – -0.3 ‰)
747 and non-ruminant adipose ($\Delta^{13}C$ > -0.3 ‰) products. Dairy residues LIK10 and SHH42 (boxed) were
748 directly dated. Residues with evidence for aquatic biomarkers (BM) are indicated. The ranges in **b** show
749 the mean ± 1 s.d. from a database of modern terrestrial reference values published in [59] and aquatic
750 reference values published in [48,58,63,69]**.** The modern reference ranges have been corrected for post-
751 industrial carbon contribution +1.3‰[70]. Analytical precision is ± 0.4‰.

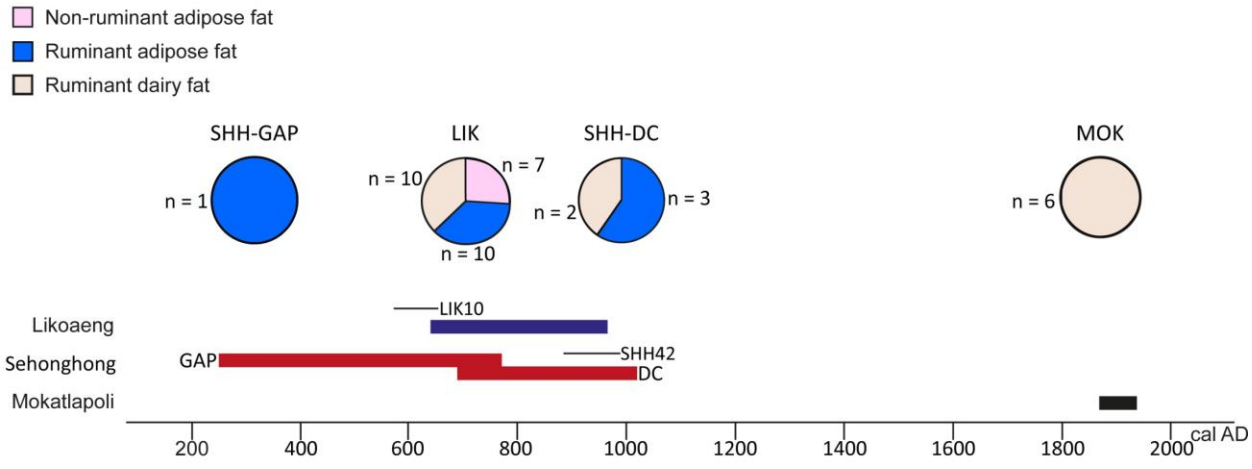


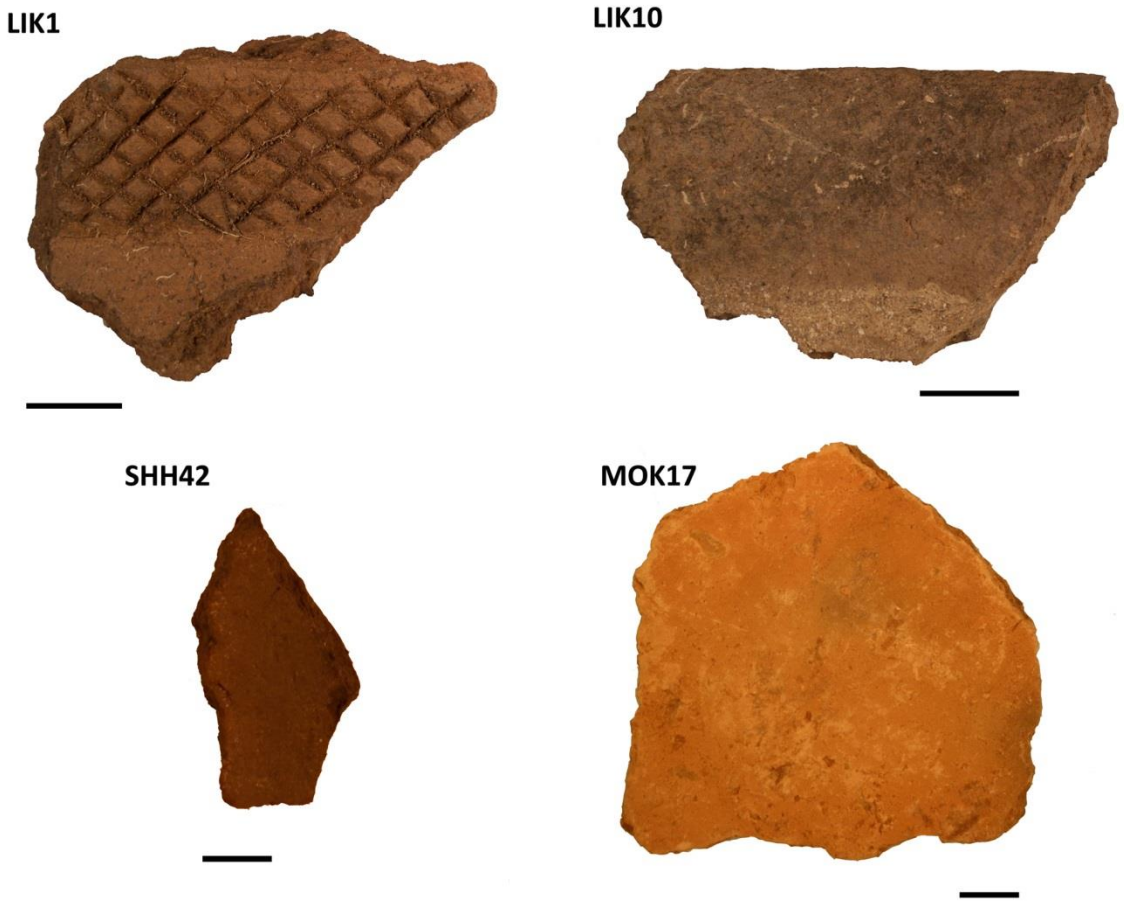
Figure 4. Timeline showing span of the layers from the three sites that were analysed in the study: the two Later Stone Age sites, Likoaeng Layer 1 (dark blue) and Sehonghong Layer GAP and Layer DC (red) (95.4% calibrated ranges of dates shown in Table 1) and the probable range of the late nineteenth-/early twentieth-century agricultural village, Mokatlapoli (see 'Sites and samples' for details). The calibrated (95%) date ranges for the combined compound-specific radiocarbon dating of fatty acids from two terrestrial dairy fats LIK10 and SHH42 are shown as black lines. The pie charts show the proportions of different animal-derived products identified from each assemblage through compound-specific stable isotope analysis.

Tables

Site	Layer	Laboratory number	Material	^{14}C age (BP)	Calibrated age range (2σ)	Notes	Reference
Likoaeng	1	GrA-23237	Bone	1285 ± 40	AD 681–884	Morphological ID: sheep/goat (ulna)	Mitchell, et al.[21]
Likoaeng	1	GrA-26831	Iron	1290 ± 30	AD 682–879		Mitchell, et al.[21]
Likoaeng	1	Pta-7877	Charcoal	1310 ± 80	AD 641–969		Mitchell, et al.[21]
Sehonghong	DC	Wk-34786	Bone – distal metapodial fragment (SHH_7355)	1130 ± 30	AD 892–1018	Morphological ID: *Ovis aries* (sheep) aDNA ID: *Redunca fulvorufula* (reedbuck)	Horsburgh, et al.[27]
Sehonghong	DC	Wk-34785	Bone – tarsal fragment (SHH_7449)	1130 ± 30	AD 892–1018	Morphological ID: *Bos taurus* (cattle) aDNA ID: *Tragelaphus oryx* (oryx)	Horsburgh, et al.[27]
Sehonghong	DC	Wk-34784	Bone – distal first phalanx fragment (SHH_7356)	1200 ± 30	AD 775–983	Morphological ID: *Bos taurus* (cattle) aDNA ID: *Tragelaphus oryx* (oryx)	Horsburgh, et al.[27]
Sehonghong	DC	Pta-6084	Charcoal	1240 ± 50	AD 685–971	This sample was published and previously attributed to Layer GAP. The new Horsburgh et al.[23] dates from Layer DC and re-assessment of the sample's stratigraphic provenance suggest that it in fact comes from DC.	Mitchell[28]
Sehonghong	DC	Wk-34787	Bone – proximal radius (SHH_7459)	5870 ± 30	4787–4581 BC	Morphological ID: *Ovis aries* (sheep). No DNA recovered. The date indicates that this cannot be from a domestic animal and that the bone must have moved upward from the underlying mid-Holocene Layer GWA.	Horsburgh, et al.[27]
Sehonghong	GAP	Pta-885	Charcoal	1400 ± 50	AD 594–771	From the original 1971 excavation of the site.	Carter, et al.[29]
Sehonghong	GAP	Pta-6063	Charcoal	1710 ± 50	AD 247–520	Associated with pressure-flaked stone projectile points.	Mitchell[28]

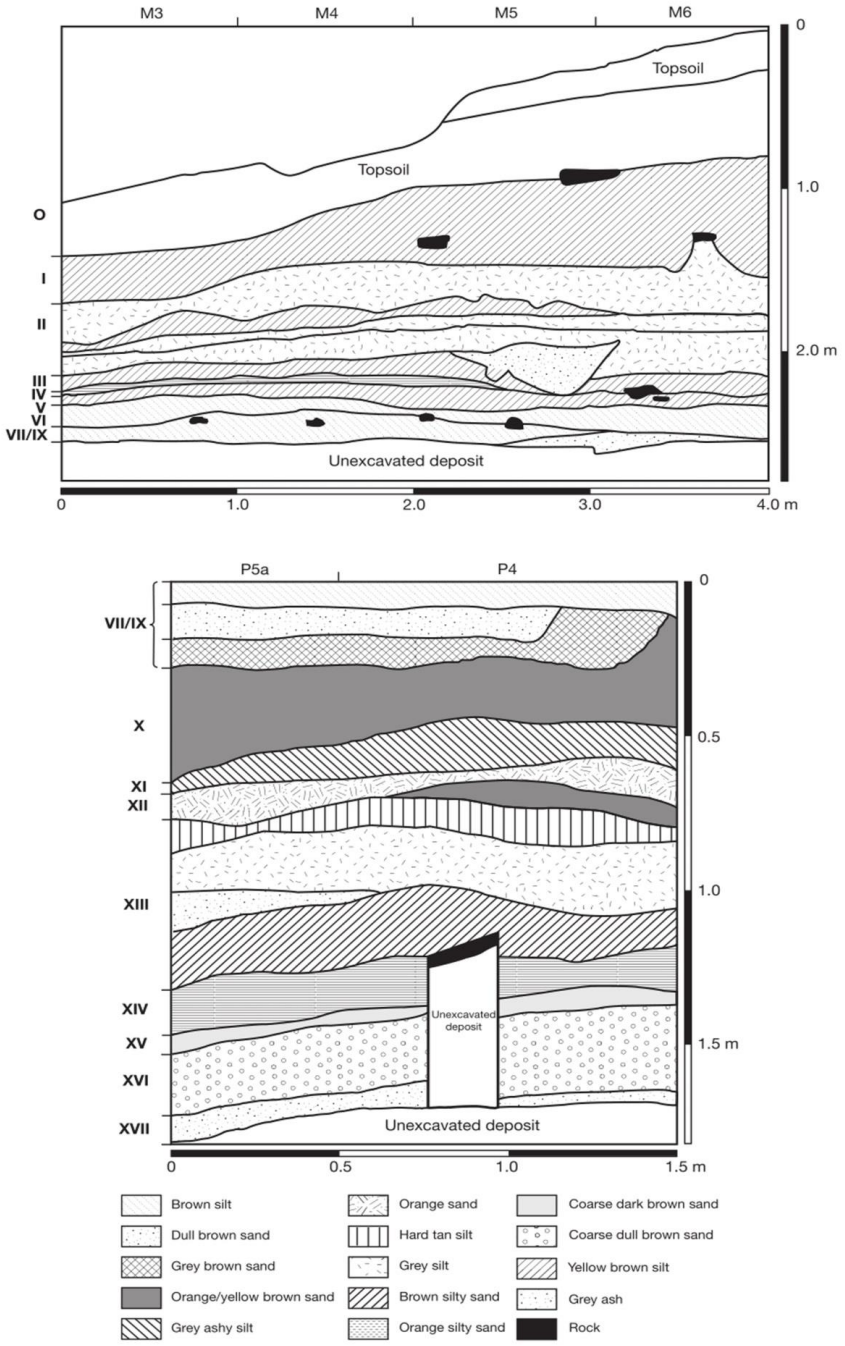
Table 1. Published radiocarbon dates from pottery-containing horizons at Likoaeng and Sehonghong, Lesotho. BP = radiocarbon years before 1950. All dates have been recalibrated using the 2013 southern hemisphere calibration curve[30] in OxCal 4.3[31].

Extended Data



Extended Data Fig. 1 | Photographs of four potsherds containing dairy residues analysed in the study. LIK1 is the EIA potsherd recovered from Layer 1 of Likoaeng. Lipids extracted from LIK10 and SHH42 were directly dated as part of the study. Scale bar is 1 cm.

Extended Data Fig. 2 | View of Likoaeng excavation looking upstream of the Senqu River (pictured in the background). The north section of the excavation is shown, and Layer 1 is marked.



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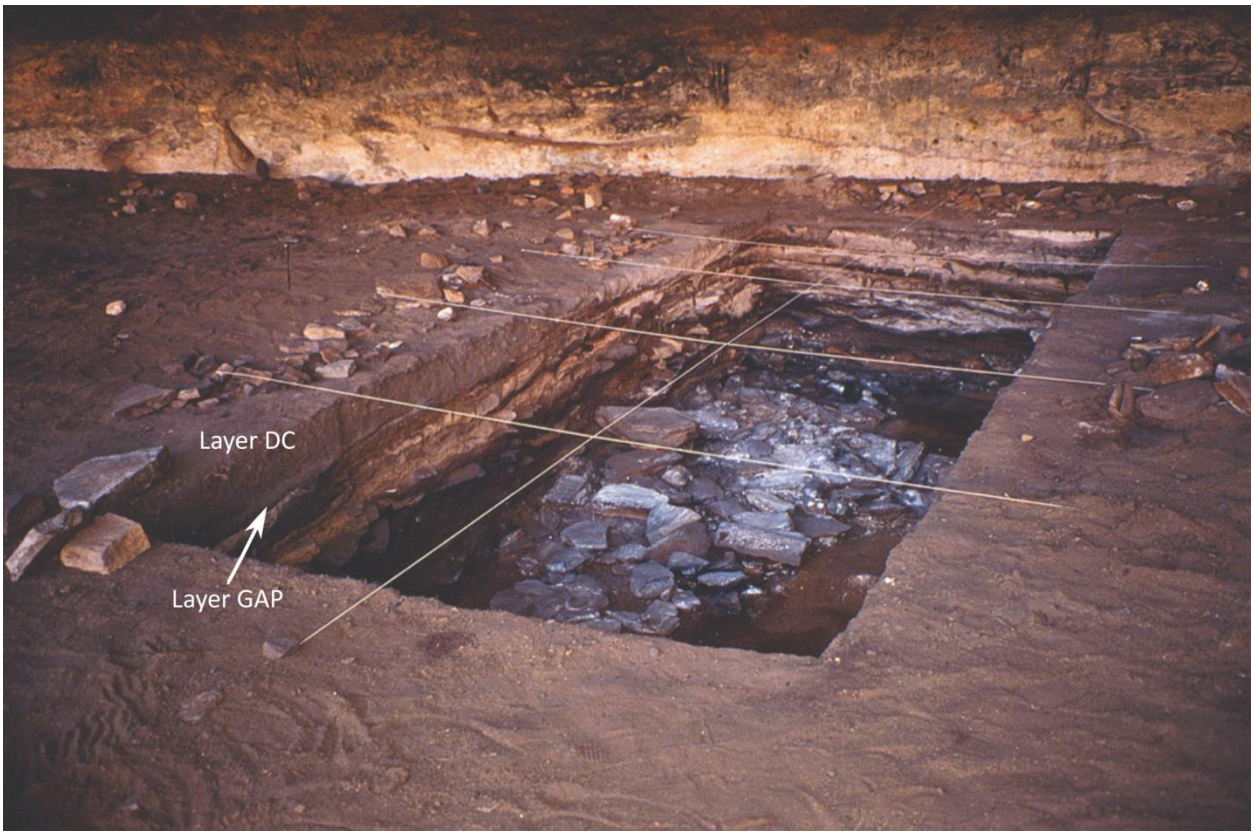
777 **Extended Data Fig. 3 | Section drawings of Likoaeng.** Layers are shown on the left side and grid
778 square references along the top. Figure modified from a previous publication23 (reprinted with
779 permission).

Extended Data Fig. 4 | View of Sehonghong rock shelter.



Extended Data Fig. 5 | Photograph of the excavation of Sehonghong rock shelter with Layers DC and GAP seen in the section.

Supplementary Information

Supplementary information

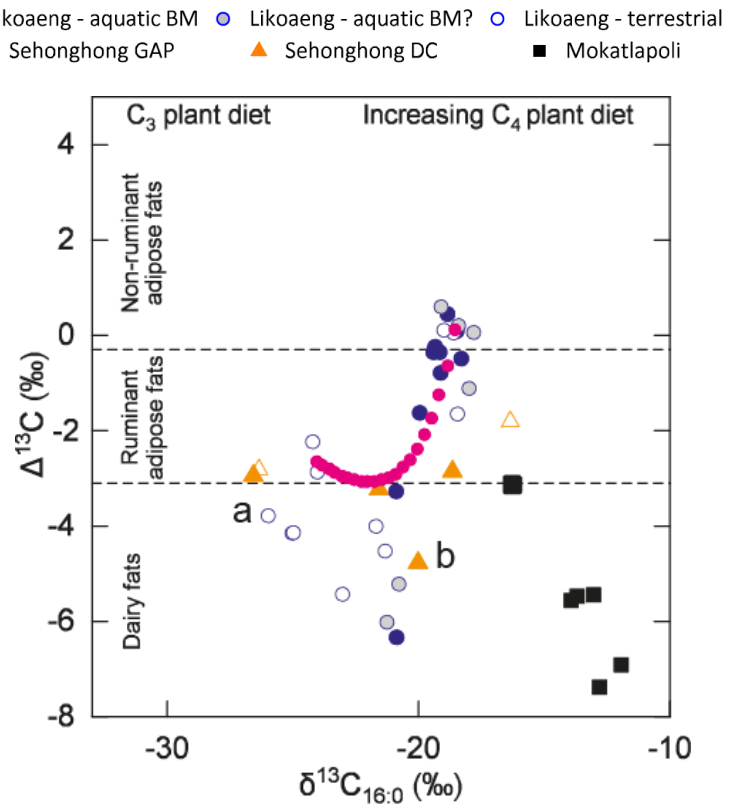
Supplementary Figures

- Supplementary Figure 1 - Theoretical mixing model of aquatic and terrestrial fats

Supplementary Tables

- Supplementary Table 1 – Information on pottery lipid extracts from Likoaeng
- Supplementary Table 2 – Information on pottery lipid extracts from Sehonghong
- Supplementary Table 3 – Information on pottery lipid extracts from Mokatlapoli
- Supplementary Table 4 – Radiocarbon dates on pottery lipids from Lesotho

Supplementary Figures



Supplementary Figure 1. Plot of the $\delta^{13}C_{18:0} - \delta^{13}C_{16:0}$ ($\Delta^{13}C$) values against the $\delta^{13}C_{16:0}$ values from potsherds from the three sites in the study (Fig. 3b in main text; a and b mark the two dairy residues directly dated in the study) with a theoretical mixing line (bright pink) superimposed over the isotopic values. Modelling was based on averages of the isotopic values obtained from non-ruminants fats ($\delta^{13}C_{16:0}$ = -18.6‰, $\delta^{13}C_{18:0}$ = -18.4 ‰) and from the more depleted group of ruminant carcass fats (as these would most greatly exaggerate any 'dairy' signal arising from mixing; $\delta^{13}C_{16:0}$ = -24.1 ‰, $\delta^{13}C_{18:0}$ = -26.7 ‰) and the published fatty acid % weight averages from 20 freshwater fish species from southern Africa (C_{16} = 24.2 %, C_{18} = 7%)[1,2]. This demonstrates that the hypothetical mixing of aquatic fats with terrestrial carcass fats based on averages of the data obtained in the study would not enter the range of ruminant dairy fats, and lie very far from the very negative $\Delta^{13}C$ values of dairy residues obtained.

References

1. Chetty, N., Reavis, S. C., Atkinson, P. M. & Van As, J. G. Fatty acid composition of some South African fresh-water fish. *South African Medical Journal* **76**, 368-370 (1989).
2. Chauke, E. *et al.* Fatty acids composition in South African freshwater fish as indicators of food quality. *Water SA* **34**, 119-126, doi:10.4314/wsa.v34i1.180885 (2008)

Supplementary Table 1. Information of extracted potsherds from Likoaeng (Y = yes, N = no, TR = ?).

Sample	Sample weight (g)	Lipid yield (mg g^{-1})	$\delta^{13}C_{16:0}$	$\delta^{13}C_{18:0}$	$\Delta^{13}C$	Residue classification	$C_{18:0}$ APAA SIM	$C_{20:0}$ APAA SIM	$C_{22:0}$ APAA SIM	Phytanic acid	Pristanic acid	TMTD	Aquatic contribution?
LIK1	2.62	0.65	-20.9	-24.2	-3.3	dairy	Y	TR	N	Y	TR		Yes
LIK2	1.20	0.10											
LIK3	1.23	0.15	-18.0	-19.1	-1.1	ruminant adipose	Y	TR	N	Y	N	N	?
LIK4	2.40	1.11	-24.2	-26.4	-2.2	ruminant adipose	Y	N	N	Y	N	N	
LIK5	1.66	0.48	-20.8	-26.0	-5.2	dairy	Y	Y	N	Y	N	N	?
LIK6	0.98	1.04	-19.9	-21.5	-1.6	ruminant adipose	Y	Y	N	Y	N	Y	Yes
LIK7	1.79	0.43	-20.9	-27.2	-6.3	dairy	Y	Y	TR	Y	N	Y	Yes
LIK8	2.21	0.45											
LIK9	3.04	0.45	-25.0	-29.2	-4.2	dairy	Y	N	N	Y	N	N	
LIK10	1.74	1.50	-26.0	-29.8	-3.8	dairy	Y	N	N	Y	N	N	
LIK11	2.27	0.05	-21.3	-25.8	-4.5	dairy	N	N	N	N	N	N	
LIK12	2.26	0.13											
LIK13	2.05	0.40	-18.8	-18.4	0.4	non-ruminant adipose	Y	Y	N	Y	N	Y	Yes
LIK14	3.26	0.07	-21.7	-25.7	-4.0	dairy	N	N	N	N	N	N	
LIK15	2.74	0.62	-21.2	-27.3	-6.0	dairy	Y	Y	N	Y	N	N	?
LIK16	3.37	0.26	-24.0	-26.9	-2.9	ruminant adipose	Y	N	N	Y	N	N	
LIK18	2.16	0.62	-23.0	-28.5	-5.4	dairy	Y	N	N	Y	N	N	
LIK19	1.97	0.22	-18.5	-20.1	-1.7	ruminant adipose	N	N	N	Y	N	N	
LIK20	1.36	0.51	-19.1	-18.5	0.6	non-ruminant adipose	Y	Y	N	Y	N	N	?
LIK21	3.34	0.26	-18.5	-18.4	0.1	non-ruminant adipose	Y	Y	Y	Y	N	N	Yes
LIK23	3.46	0.41	-17.8	-17.8	0.1	non-ruminant adipose	Y	Y	N	Y	N	N	?
LIK24	3.19	na	-18.6	-18.6	0.0	non-ruminant adipose	Y	N	N	Y	N	N	
LIK25	2.91	na	-19.0	-18.9	0.1	non-ruminant adipose	Y	N	N	Y	N	N	
LIK26	3.55	na	-19.4	-19.8	-0.4	ruminant adipose	Y	Y	TR	Y	N	N	Yes
LIK27	3.53	na											
LIK28	3.61	na	-25.0	-29.1	-4.2	dairy	Y	N	N	Y	N	N	
LIK29	1.21	0.21	-18.4	-18.2	0.2	non-ruminant adipose	Y	TR	N	Y	N	N	?
LIK30	3.70	0.05	-19.3	-19.6	-0.3	ruminant adipose	Y	Y	TR	Y	N	TR	Yes
LIK31	2.42	0.19	-18.3	-18.8	-0.5	ruminant adipose	Y	Y	TR	Y	N	N	Yes
LIK32	3.01	na	-19.1	-19.9	-0.8	ruminant adipose	Y	Y	Y	Y	N	N	Yes
LIK33	1.23	na	-19.1	-19.5	-0.4	ruminant adipose	Y	Y	TR	Y	N	Y	Yes

Supplementary Table 2. Information of extracted potsherds from Sehonghong rock shelter.

Sample	Layer	Sample weight (g)	Lipid yield (mg g^{-1})	$\delta^{13}C_{16:0}$	$\delta^{13}C_{18:0}$	$\Delta^{13}C$	Residue classification	$C_{18:0}$ APAA SIM	$C_{20:0}$ APAA SIM	$C_{22:0}$ APAA SIM	Phytanic acid	Pristanic acid	TMTD	Aquatic contribution?
SHH28	GAP	1.78	0.05	-24.8	-24.0	0.8	Not predominantly animal derived	N	N	N	N	N	N	
SHH29	GAP	1.94	0.03											
SHH30	GAP	2.77	0.94	-16.4	-18.2	-1.8	ruminant adipose	N	N	N	N	N	N	
SHH31	GAP	2.99	0.06											
SHH32	DC	2.49	0.06											
SHH33	DC	2.15	10.33	-26.4	-29.2	-2.8	ruminant adipose	N	N	N	N	N	N	
SHH34	DC	2.12	0.19	-18.7	-21.5	-2.9	ruminant adipose	Y	N	N	Y	N	N	
SHH35	DC	2.15	0.03											
SHH36	GAP	2.19	0.11											
SHH37	GAP	1.42	0.17											
SHH38	GAP	1.16	0.05											
SHH39	GAP	2.63	0.01											
SHH40	DC	3.30	0.04											
SHH41	DC	2.08	2.99	-21.6	-24.8	-3.2	dairy	Y	TR	N	Y	N	N	?
SHH42	DC	1.58	1.24	-20.0	-24.8	-4.8	dairy	Y	Y	TR	Y	N	N	
SHH44	DC	3.03	0											
SHH45	DC	1.67	2.60	-26.6	-29.5	-2.9	ruminant adipose	Y	N	N	Y	n	n	

Supplementary Table 3. Information for extracted potsherds from Mokatlapoli.

Sample	Sample weight (g)	Lipid yield (mg g^{-1})	$\delta^{13}C_{16:0}$	$\delta^{13}C_{18:0}$	$\Delta^{13}C$	Residue classification	$C_{18:0}$ APAA SIM	$C_{20:0}$ APAA SIM	$C_{22:0}$ APAA SIM	Phytanic acid	Pristanic acid	TMTD	Aquatic contribution?
MOK1	2.04	0.01	-24.4	-21.1	3.3	Not predominantly animal derived	N	N	N	N	N	N	
MOK2	3.56	0											
MOK3	3.39	0.01											
MOK4	2.67	0.02											
MOK5	3.38	0.21	-13.0	-18.5	-5.4	dairy	N	N	N	Y	N	N	
MOK6	2.96	0											
MOK7	3.61	0.01											
MOK8	2.11	0											
MOK9	1.85	1.92	-13.9	-19.5	-5.6	dairy	Y	?N	N	Y	N	N	
MOK10	3.66	0.02											
MOK11	2.79	0.01											
MOK12	1.99	0.94	-11.9	-18.8	-6.9	dairy	N	N	N	Y	N	N	
MOK13	3.74	0											
MOK14	1.92	3.69	-12.8	-20.2	-7.4	dairy	N	N	N	Y	N	N	
MOK15	2.56	0.01	-23.8	-22.6	1.2	Not predominantly animal derived	N	N	N	N	N	N	
MOK16	3.07	0					N	N	N	N	N	N	
MOK17	3.33	0.04	-16.3	-19.4	-3.1	dairy	N	N	N	N	N	N	
MOK18	2.30	0.04	-13.5	-14.5	-1.1	Not predominantly animal derived	N	N	N	N	N	N	
MOK19	3.56	0.01	-15.0	-16.2	-1.2	Not predominantly animal derived	N	N	N	N	N	N	
MOK20	2.21	0.05	-13.7	-19.2	-5.5	dairy	N	N	N	N	N	N	
MOK21	2.02	0.03											
MOK22	3.34	0.01											
MOK23	2.65	0.01											
MOK24	2.51	0.02											
MOK25	3.82	0.01											
MOK26	2.52	0.12											
MOK27	3.24	0.03	-18.6	-18.8	-0.2	Not predominantly animal derived	Y	N	N	N	N	N	

Supplementary Table 4. Radiocarbon dates on pottery lipids from Lesotho.

Laboratory nr.	sample label	^{14}C age (y) BP	Replicate agreement (σ range)	Combined age (y) BP	Calibrated range (68.2 % probability)	Calibrated range (95.4 % probability)
BRAMS-2612.1.1	SHH42-$C_{16:0}$	1155 ± 34	1 σ	BRAMS-2612: 1161 ± 28	AD 895-935 (41.8 %) AD 955-980 (26.4 %)	AD 885-990
BRAMS-2612.1.2	SHH42-$C_{18:0}$	1169 ± 36				
BRAMS-2613.1.1	LIK10-$C_{16:0}$	1504 ± 29	X	-	-	-
BRAMS-2613.1.2	LIK10-$C_{18:0}$	1734 ± 28				
BRAMS-2613.2.1	LIK10-$C_{16:0}$	1438 ± 30	2 σ	BRAMS-2613: 1481 ± 27	AD 600-644	AD 579-654
BRAMS-2613.2.2	LIK10-$C_{18:0}$	1516 ± 30				